4.2 *Time domain results from individual runs*

The first results obtained were plots of run data vs. time. Figure 4.1 shows an example, that of 1 active call with only rural wideband noise as interference:

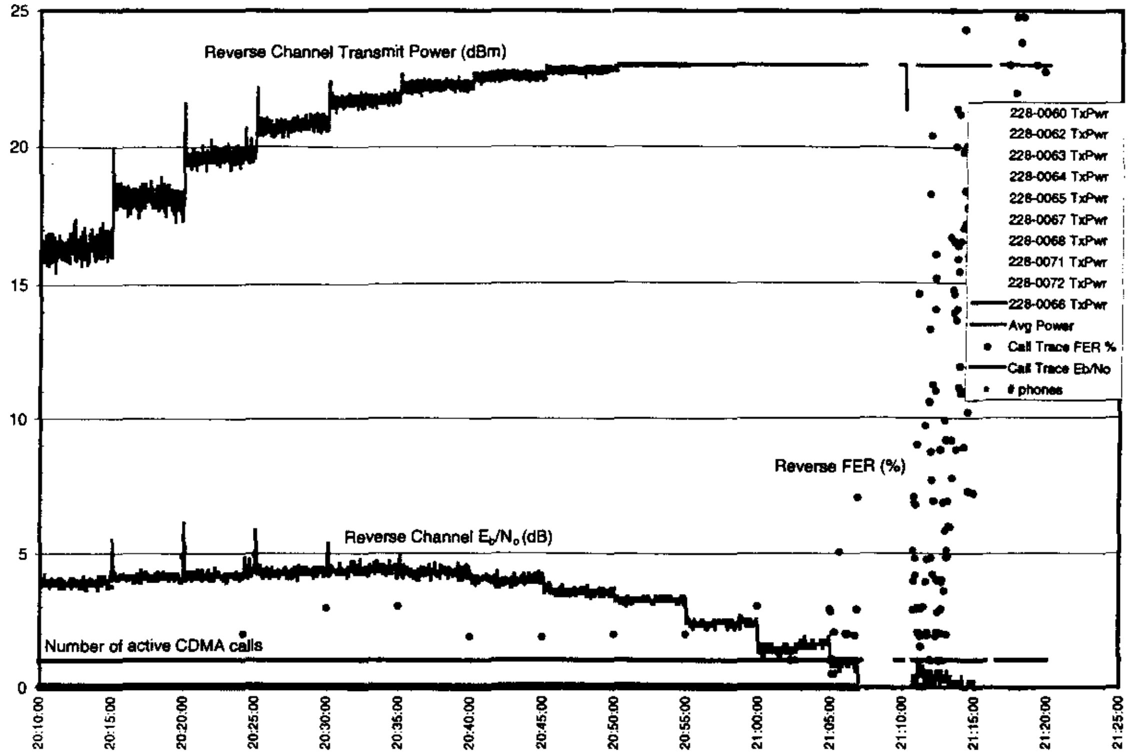


Figure 4.1 Run data, 1 active call, Rural background noise only.

This figure shows time aligned data for reverse transmit power, FER, E_b/N_o and the number of active calls vs. time. The run began at 8:10 PM (20:10:00) on the time axis, and one call is confirmed to be up by the green trace ("# phones") having value '1'. The first data point was 5 minutes long, running until 20:15:00. At that time, the step attenuator was advanced 1 dB, and the phone transmit power (visible as a blue trace) jumps from roughly 16.5 dBm to 18.25 dBm. The blue trace, ("Avg Power") overlays the red trace ("228-0066 TxPwr") perfectly, so the red trace is not visible. This is because only one phone is active, and the average is exactly equal to the power of that one phone at all times. Every 5 minutes thereafter, the step attenuator was increased another 1 dB, until the call dropped and would not re-establish.

The moment at which the step attenuator was advanced is clearly visible due to a momentary upward glitch in FER, E_b/N_o, and transmit power. These simultaneous glitches in the data were used to manually verify and correct the time alignment. In addition, they were used as markers to identify any transition points that were slightly different from those manually logged. If a log entry approached 5 seconds of error, the run logfile was corrected to assure the accuracy of the postprocessed, time averaged data, and the run was reprocessed.

This run shows exactly the sort of data that had been hoped for... dynamic power control is active at the beginning of the run and phone transmit power steps upward with increasing attenuation. the E_b/N_o remains essentially constant, and FER remains zero (neglecting the transients at attenuation changes). At 20:40, the phone average power is within 1 dB of maximum, and E_b/N_o begins to drop, slowly at first. Transmit power reaches an unwavering +23 dBm at 20:50:00. At that point, it was out of power and the E_b/N_o began stepping downward roughly 1 dB for each 1 dB further increase in path attenuation.

As E_b/N_o fell below 2 dB, FER began to pick up, until the call was lost at about 21:07. Attempts to re-establish the call past that point were largely futile, with high FERs and very low E_b/N_o values. The run was ended at 21:20:00.

What is interesting is that even though the system was set to achieve zero FER (when possible), it was able to 'sneak down' the E_b/N_o to about 4 dB rather than the 7 dB typically used as a design goal. This happened in the first seconds of the call. The dynamic power control algorithm turned out to include a frame error rate target, and it sought lower transmit power levels so long as the FER remained acceptable (0%). 4 dB E_b/N_o satisfied this drive because the static test hookup did not simulate fading, which normally causes momentary dropouts in E_b/N_o.

<u>The lack of fading, leading to a lower than normal E_b/N_o actually works against the AirCell case.</u> Normally, the presence of fading on the channel would cause some frame errors at higher average E_b/N_o values. The AMPS interference impact would be partially masked by the momentary, deep fades (which cause frame errors anyway) and the higher average E_b/N_o. (During the intervals that the E_b/N_o is larger - when no fade is occurring - a small impact *would not* cause as many frame errors). The fading environment would lead to a more gradual rolloff in performance. In this figure, the lack of fading made the transition from perfect FER to *a dropped call* take place in only 1-2 dB of path attenuation… and the dropped call happened 3 dB after path attenuation had caused the phone to reach +23 dBm average transmit power. Thus, the nonfading environment exhibits very unforgiving, threshold-like behavior.

Figure 4.2 through Figure 4.7 show the same rural case, as traffic loading was increased to two, four, six, eight, ten and twelve calls:

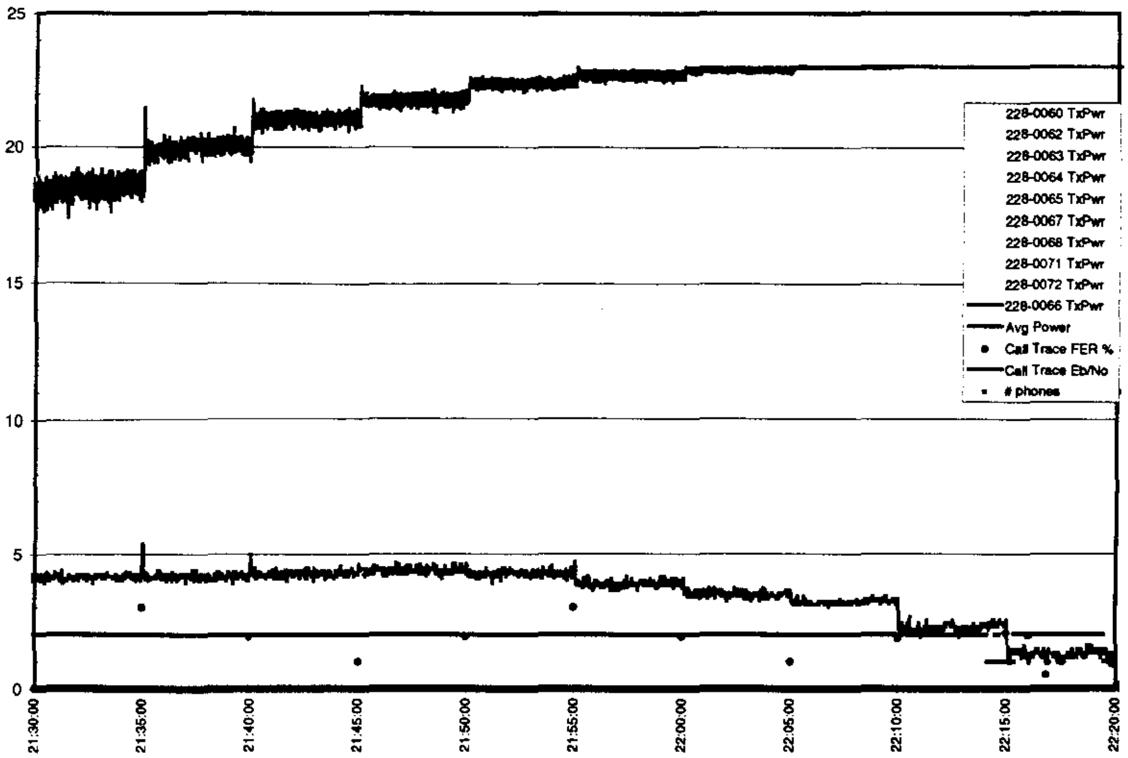


Figure 4.2 Run data, 2 active calls, Rural background noise only

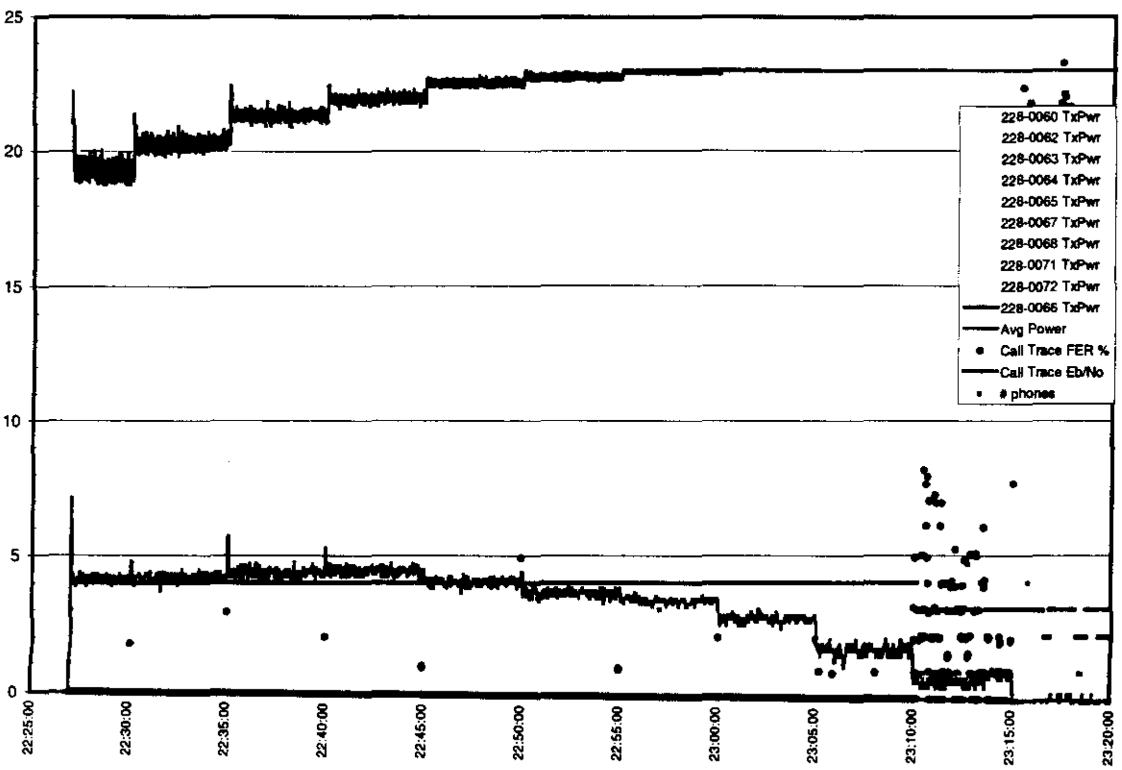


Figure 4.3 Run data, 4 active calls, Rural background noise only

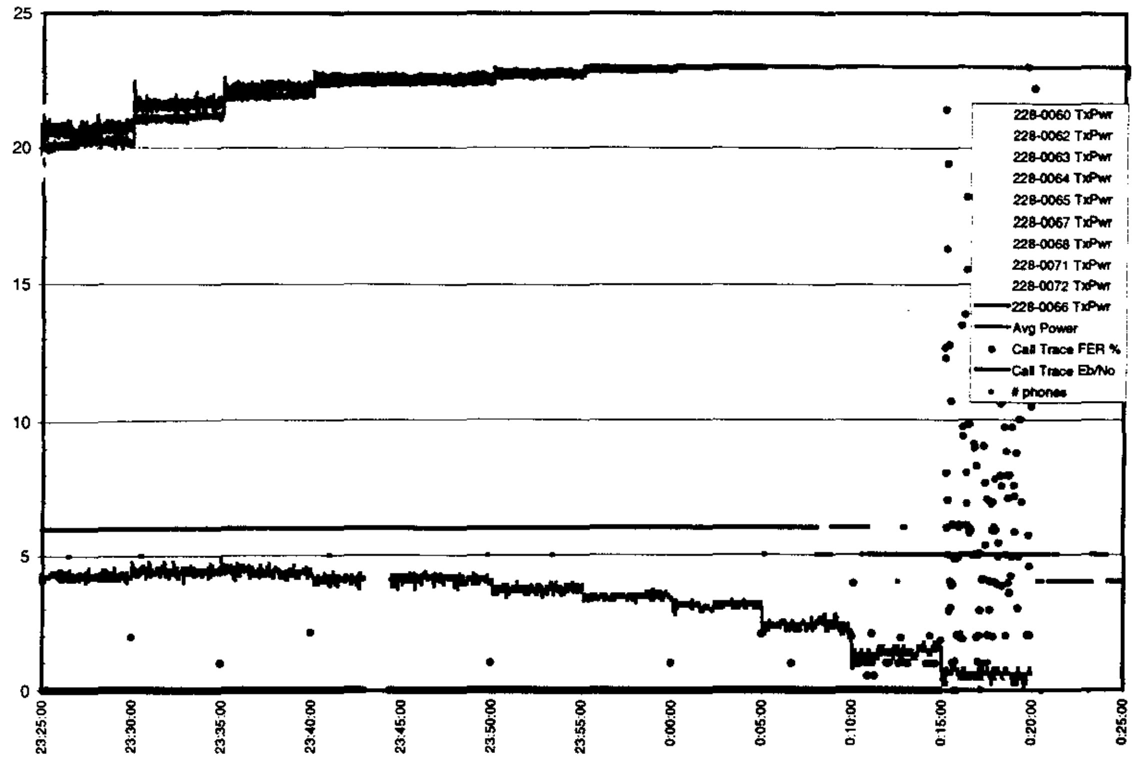


Figure 4.4 Run data, 6 active calls, Rural background noise only

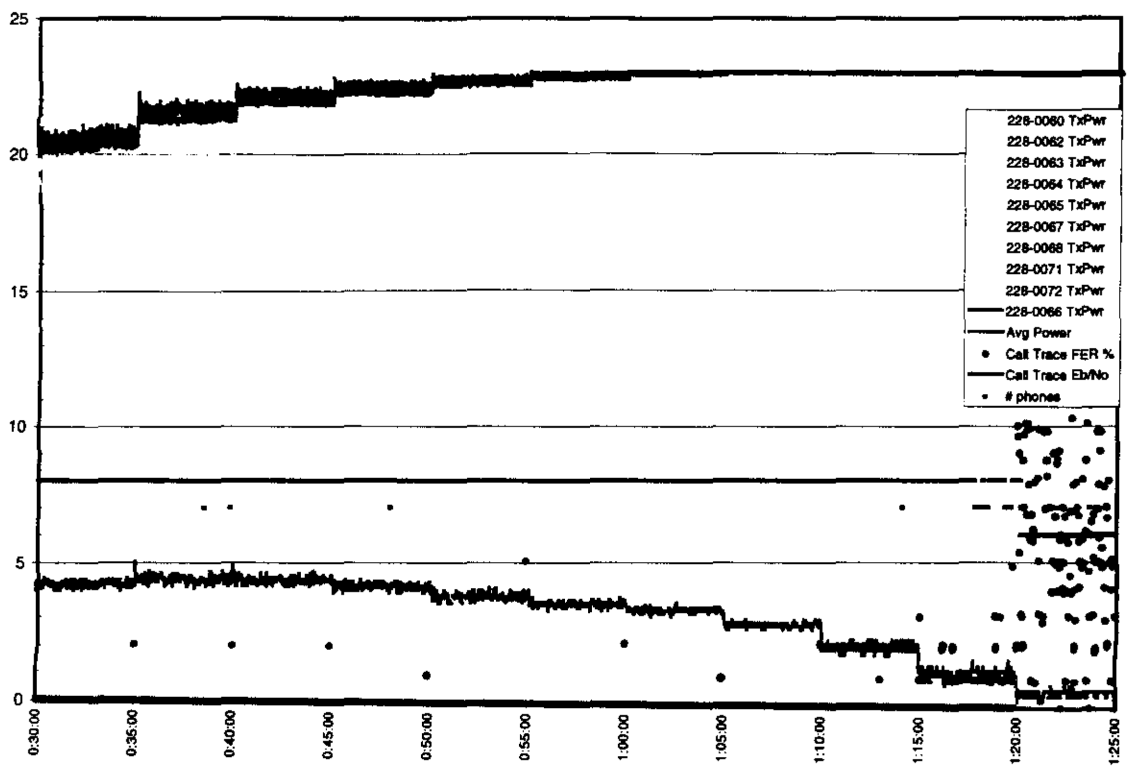


Figure 4.5 Run data, 8 active calls, Rural background noise only

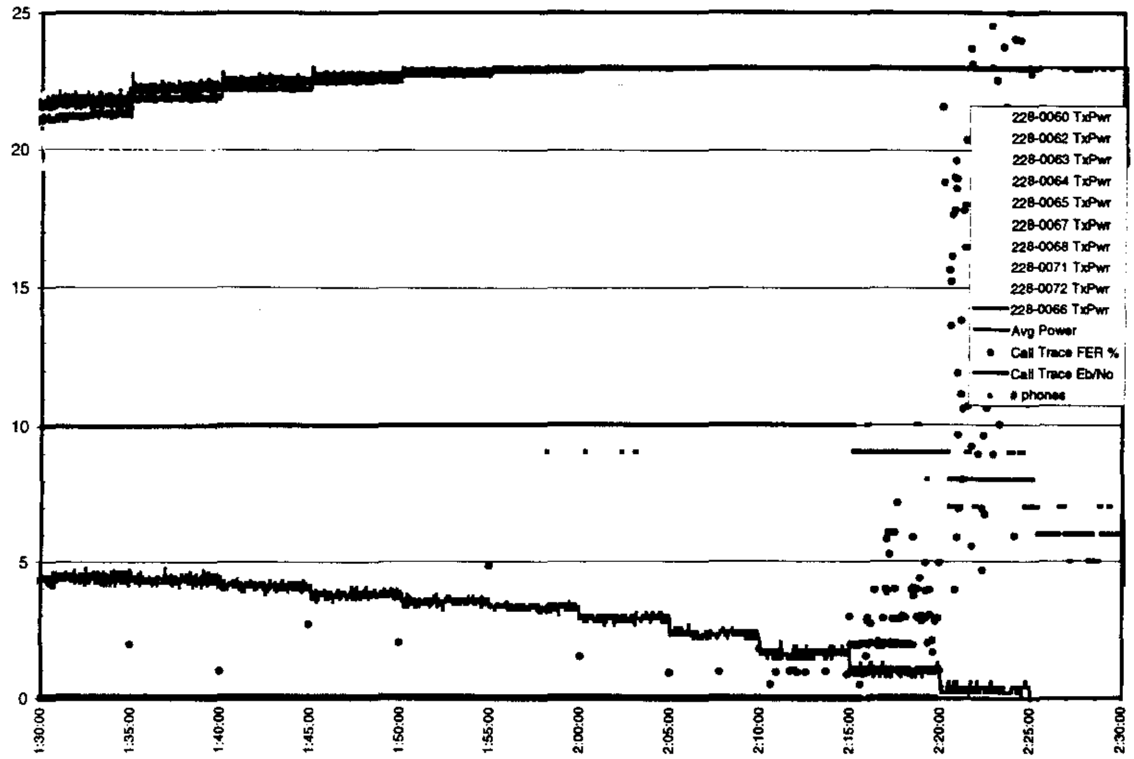


Figure 4.6 Run data, 10 active calls, Rural background noise only

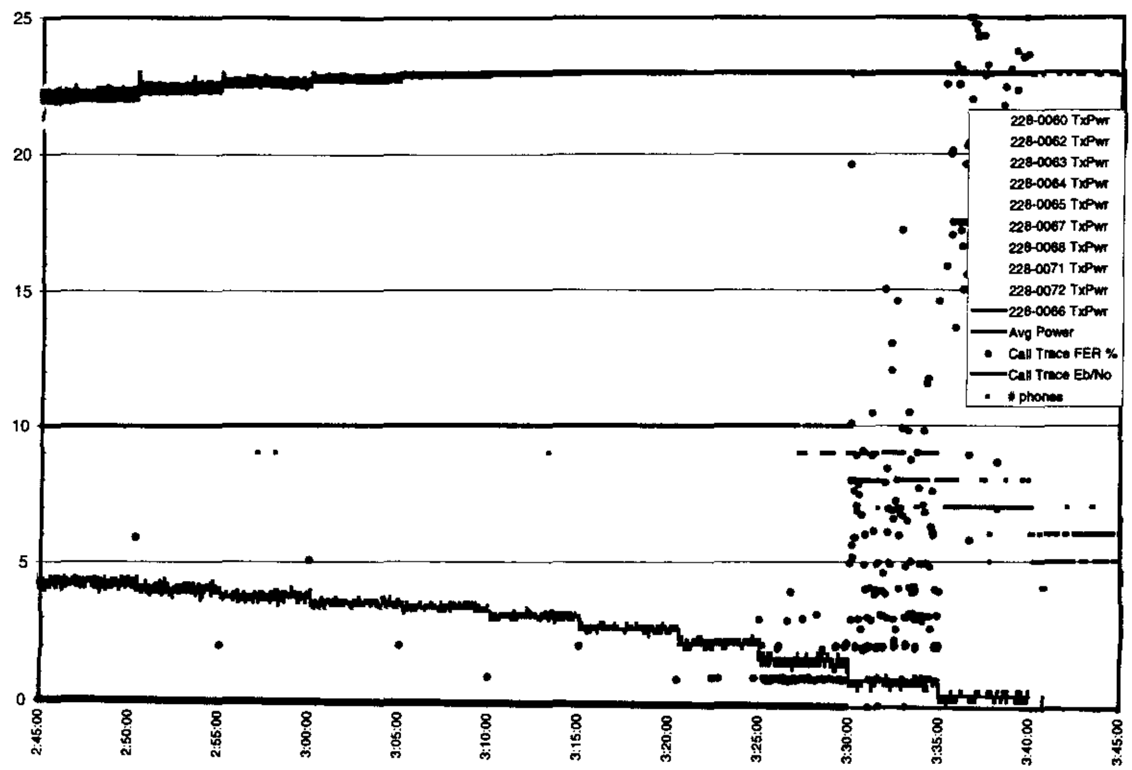


Figure 4.7 Run data, 12 active calls, Rural background noise only

4.3 Averaging of time domain data

The data depicted in Figure 4.1 through Figure 4.7 above is representative. The plots depicting all runs are in Appendix D Time Domain Run Results. This time aligned data was reduced to obtain average values for each path loss step. Each 1 dB step in path loss and its associated averaging period produced a 'data point' as discussed below. The first few (baseline) runs used 4-5 minute averaging times for each data point, but later runs used 2 minute averaging times. The first and last 10 seconds of each data point averaging period were ignored in postprocessing to reduce the effect of the glitches at path loss transitions, thus the averaged data points present measurements of steady-state performance.

A two-minute average with the first and last 10 seconds of data discarded resulted in 100 seconds of useful data averaged as follows:

CDMA FER

The RF call trace reported FER as a percentage for the frames received every 2 seconds. As 50 frames/second were sent, each two second report represented an average over approximately 100 frames. One frame error thus approximated 1% FER for any reporting interval, and FER appears quantized in roughly 1% steps in the figures, as one would expect. A two minute averaging period thus represents an average of 5000 individually counted frames.

CDMA E_b/N_0

As with FER, E_b/N_0 data was derived from RF call trace data, and represents an average over 5000 frames of data.

CDMA Reverse Transmit Power

From one to ten instrumented phones were used for each run, depending upon the desired traffic loading. Each phone reported transmit power 50 times per second, as the average over a transmitted frame. (Actual reverse link fast power control took place at an 800 Hz rate, so each report represented 16 intervals in which power was adjusted ±1 dB.) The 50 Hz reports were averaged to obtain 1 second averages (shown in the figures above), which were then averaged over 100 seconds of each 120 second data point. Mathematically, successive averaging is valid so long as consistent (in this case dB) units are used. Thus, each data point can be regarded as the average of 80,000 fast power adjustments or 5,000 frames. When more than one phone transmitted, the average power reported (the blue trace in the figures above) represents a multiple of these numbers; in the 10 call case for instance, a two minute data point represents the average of 800,000 fast power adjustments, or 50,000 transmitted frames.

Based on the above, a two-minute 'data point' was considered to be statistically significant average for the required parameters. Data *was not averaged* toward the result for a data point if the number of calls up (shown in the figures above as a light green trace) did not agree with the specified number for the run. Calls were considered to be up *only* when the phone reported full rate Markov frames being transmitted. Thus, access probes and call setup transmissions during intervals when one or more calls had been dropped and not yet re-established were not considered in the averaged data points. In other words, if less than the specified number of calls were up, reverse channel self-interference levels were lower than intended, so all data from such intervals was discarded in postprocessing.

Reverse link transmit power data points for the Rural noise case showed that as the traffic load increased, the system-generated reverse channel background noise did also, resulting in increased subscriber unit transmit power. The trend is clear in Table 4.1:

Table 4.1 Rural Noise floor, reverse channel power vs. call loading

Number of CDMA calls	Average Subscriber Transmit Power (dBm)
1	16.34
2	18.72
4	18.98
6	20.15
8	20.28
10	21.24
12	22.02

The *trend* that increased numbers of calls increased the subscriber unit transmit power was expected, and did manifest. Other expected trends, such as the interaction between transmit power, path loss, FER, and E_b/N_0 also appeared to be correct in overall form.

Similar trends were also evident with Suburban, Urban, and Dense Urban Noise floors, as shown in Table 4.2 through Table 4.4 below. Time domain plots for each run Suburban to Dense Urban appear in Appendix D Time Domain Run Results.

As the noise floor was increased, progressing from Rural through Suburban, Urban, and Dense Urban cases, it was found that the starting path loss for each run had to be decreased to assure that each run began at a reverse power level allowing dynamic power control to operate. Thus, Table 4.1 through Table 4.4 represent progressively lower path losses as one would expect; progressively smaller nominal cell radii (less allowable path loss) usually results from the link budget as land usage progresses from Rural through Dense Urban cases.

The Suburban case began at the same initial path loss as the Rural case, and had to be reduced 3 dB between the 4 and 6 call runs. The Urban case initial path loss was set 9 dB lower than the Rural case for each run. The Dense Urban case 1 and 4 call runs began at 15 dB less path loss than Rural, and the 6-12 call runs began at 19 dB lower path loss than the Rural case.

(That is, in the Suburban and Dense Urban cases, it was necessary to change starting path attenuation as traffic load increased past 4 Markov calls, as noted in the tables. Data values within those tables were normalized to compensate for this change in starting path loss, as indicated.

Table 4.2 Suburban Noise floor, reverse channel power vs. call loading

Number of CDMA calls	Average Subscriber Transmit Power (dBm)
1	16.74*
4	18.06*
6	18.75
8	20.16
10	20.86
12	22.01

*Adjusted to account for reverse path attenuator change between 1-4 and 6-12 call runs
(A 3 dB attenuator was removed, reducing the minimum path loss used in the 6-12 call runs. The 1 and 4 call transmit powers are adjusted down by 3 dB to reflect the same path loss as the 6-12 call runs.)

Table 4.3 Urban Noise floor, reverse channel power vs. call loading

Number of CDMA calls	Average Subscriber Transmit Power (dBm)
1	19.78
4	20.27
6	21.12
8	21.83
10	22.20
12	22.55

Table 4.4 Dense Urban Noise floor, reverse channel power vs. call loading

Number of CDMA calls	Average Subscriber Transmit Power (dBm)
1	19.88
4	20.42
6	20.92*
8	21.75*
10	22.43*
12	21.73*

*Adjusted +6 dB to account for reverse path attenuator change between 1-4 and 6-12 call runs

4.4 Data grouping into test cases

Table 4.1 through Table 4.4 present only the data points taken for points at the beginning of individual runs. A number of data points resulted from each run, one for each reverse attenuation step tested. The next postprocessing step was to assemble these data points to describe performance metrics as surfaces in three dimensions.

One can consider an XYZ coordinate set in which the X and Y axes represent path loss and traffic loading. The Z axis is then used to represent the metric being considered, such as reverse channel operating point (phone transmit power), FER, or E_b/N_o. A surface plot depicting the reverse channel operating point for the rural background noise case is shown in Figure 4.8.

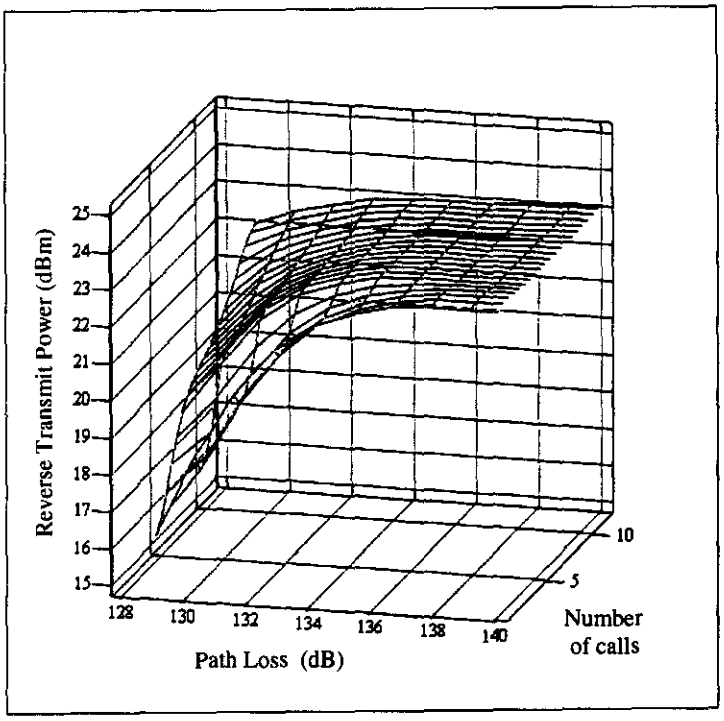


Figure 4.8 Reverse operating point surface plot, Rural background noise

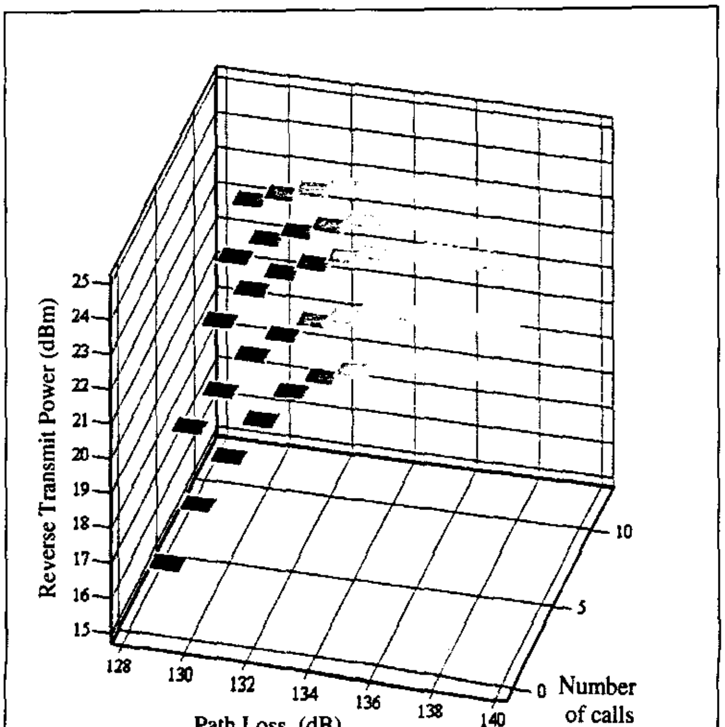


Figure 4.9 Reverse operating point patch plot, Rural background noise

Figure 4.8 shows the surface fit performed by MathCAD using the individual data points shown in Figure 4.9, which is a 'patch plot' (also produced in MathCAD). In the 'patch plot' each individual square depicts one measured data point. Data from five different runs are visible; 1, 4, 8, 10, and 12 active calls. The surface plot approach provides a better visualization of the data, but it should be noted that it is a fit to the data; it depicts interpolations between and extrapolations of the actual experimentally measured points.

The path loss depicted is the *total* path loss from phone to site receive reference point. Thus, referring to the time domain plots, the points at which calls dropped are depicted as 140 dB path loss for one call and 138 dB for twelve calls, respectively. This indicates that calls drop between -115 and -117 dBm at the receiver input, respectively.

Assuming a 14.4 kHz channel information bandwidth and the -162 dBm/Hz rural noise level and a receiver noise figure of approximately 6 dB, the noise floor is approximately -119.5 dBm. In practice, A/D conversion and direct sequence despreading is usually slightly suboptimal, giving up perhaps 1 dB of performance, so the -117 dBm call drop point for a single call is about 1.5 dB E_b/N_o. This is reasonable, and agrees with the 1 dB E_b/N_o indicated in Figure 4.1 when call drop occurred. This provides a confidence cross-check that path loss measurements were correct and the CDMA receiver system was functioning properly.

Based on this observation, it would appear that at least -116 dBm CDMA signal level is necessary for FER to drop below 1% in a *static,* nonfading environment.

Some expected trends again emerged in the figures; As path loss increased, transmit power increased...until the +23 dBm subscriber unit transmit power limit was reached. (Increasing path loss in the laboratory environment is analogous to increasing range in the field.) As call loading increased, so did transmit power for any given path attenuation, until the +23 dBm maximum power was reached. (Nominal cell range is typically reduced at full traffic load in a CDMA system.) The path loss resulting in dropped calls decreased with increasing traffic load, as theory predicts.

E_b/N_o can also be plotted in the same format.
Figure 4.10 is a surface plot of FER data for the rural background noise case:

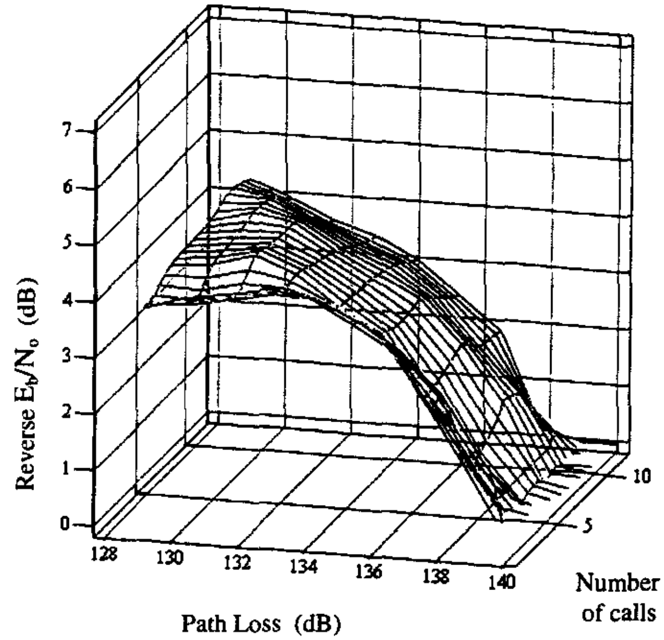


Figure 4.10 E_b/N_o surface plot, Rural background noise

Figure 4.10 illustrates the trends that theory predicts as well. As path loss increases, E_b/N_o remains essentially constant for the 1 and 4 call cases, until approximately 134 dB path loss is reached. As this point is reached (and the reverse operating point is approaching +23 dBm), E_b/N_o begins to decline, and as the transmitter runs out of power, E_b/N_o decreases dB for dB with increases in path loss. At high traffic loading (8 or more test calls), the minimum path loss depicted isn't quite low enough to manifest the 'flat' E_b/N_o region. The 'breakpoint' is moving diagonally towards the back corner of the plot, and varies with loading, as theory suggests.

Plotting FER in the same manner yields consistent results, as shown in Figure 4.11. FER remains fixed at zero as it should (since this was how the system was configured to operate) until E_b/N_o falls to approximately 2 dB. Somewhere between 2 dB and 1 dB E_b/N_o, FER spikes rapidly and the call drops. This is likely a function of the coding structure used in IS-95: the combination of block and convolutional codes makes the protocol very robust, correcting frame errors until multiple errors per frame precludes correction...as this point is reached and passed, error correction breaks down, the FER increases rapidly, and the call is dropped. Since the FER deterioration is *so* rapid, the FER metric is not a useful means for examining the potential interference effects of co-channel AirCell operation. FER data tended to confirm *when* call drops were likely to take place, but it provided little insight in itself. FER simply rose too abruptly to be a useful metric for call quality degradation. As a result, the FER data is not examined in detail in this report, other than to present it in the appendices.

The rapid FER 'break' is also (to some degree) a result of the static path loss environment. In a fading environment, the coding and interleaving structure used in IS-95 exhibits a more gradual degradation in FER, because bit errors due to fades are distributed by the interleaving process. *The static path loss case embodied by this test provides no advantage to the AirCell case.*

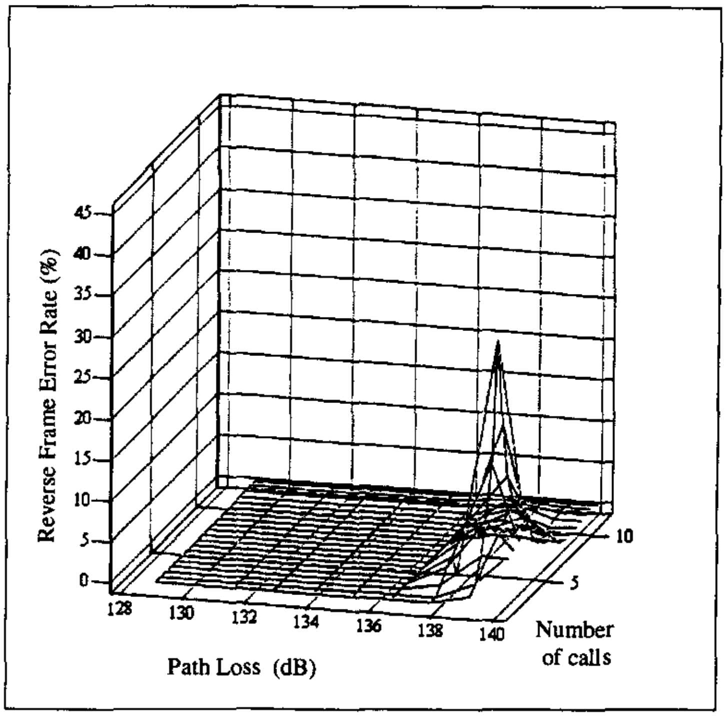


Figure 4.11 Reverse FER, surface plot, Rural background noise

Likewise, E_b/N_0 data obtained in this test cannot be mapped directly into call quality degradation until a call is very close to dropping. Mr. Hall, an author of this report, has extensive experience developing advanced algorithms for automated mapping of call quality metrics to Mean Opinion Score (a human panel evaluation of voice quality on cellular links). These algorithms are used in commercial products that evaluate cellular and PCS call quality. Based on firsthand experience, E_b/N_0 *does not* correlate with perceived voice quality in a reliable fashion. The *nature* of the errors, the duration and periodicity of fades, etc. appear to dominate the effect that errors have on the vocoder and hence the quality reproduced speech... Thus, E_b/N_0 data was not studied in detail herein, other than to present it in the appendices, and to note that it jointly varied with other metrics as expected, and tended to confirm that the overall system interaction being measured behaved as expected.

The primary metric used herein is CDMA reverse channel operating point; subscriber unit transmit power. CDMA systems actively adjust subscriber unit transmit power to cancel the effect of noise and interference until there is no more power. Of the metrics measured and considered, reverse channel operating point is the *only* one which provides a measure of interference impact when a CDMA system is *not* already in trouble; that is, an impact can be measured while calls are still being carried with nominal voice quality. FER increases and E_b/N_0 decreases due to interference *only* manifest when power management is 'maxed out' and a call is already beginning to be degraded. Arguably, reverse operating point *does not* change when the system is out of power, but in such a situation it is valid to observe that E_b/N_0 will be degraded dB for dB with increasing interference impact (calculated by extrapolation beyond the active power control range).

Thus, by using reverse operating point, it's possible to make observations under normal call quality conditions and extrapolate into regions where degradation or call drops occur.

The terrestrial propagation environment is important in judging the significance of interference impact; calls are subjected to fades of varying depth, from a few dB to tens of dB. An impact that changes operating point by an amount substantially less than typical fading is unlikely to be subjectively observable *except* in situations where no more power is available and fades mean increased frame errors and decreased voice quality. In the latter situation, a call is already being degraded by every substantial fade, so voice quality is *already* arguably unacceptable, and interference impacts would have to approach typical fade magnitudes to be observable.

If the impact of an interferer is masked by the typical operating environment, one can reasonably argue that "a difference which makes no difference *is no difference*." That is, one can argue that operating point impacts less than about a dB or two are ***very*** unlikely to be observed by subscribers.

4.5 Operating point impact calculation

Characterizing the CDMA system operating point vs. path loss in the presence of a man-made noise floor, such as the rural case illustrated above is not the final step in evaluating the collected data. The critical step is the calculation of the *impact* due to the presence of AMPS signals, such as those from AirCell operation.

The operating point impact is defined as the *change* in reverse channel (subscriber unit) transmit power due to the presence of AMPS interferers. To calculate this impact, two sets of runs were made, identical in all controllable aspects (path attenuation, wideband noise level, traffic loading, etc.). One set of runs included the three AMPS signals, and the other was a baseline with wideband noise only. Point by point, at identical traffic loading and path attenuation, the 'baseline' operating points were subtracted from the 'with interference' points and the difference (rise) in reverse operating point due to interference was calculated.

The resulting data is presented in surface plot form, as illustrated below. Figure 4.12 shows operating point impact for the '2 dB' calculated impact case shown in Table 3.1 . Later in this report, impacts calculated in this way are termed 'long term' data.

Note that discussing the '2 dB case' is something of a misnomer. It refers to the a priori calculation of interference levels *expected* to cause a 2 dB impact. The measured impact for the 1 call case (for which the impact was calculated) is 1.8 dB at the minimum path loss tested. As the path loss increases and the subscriber unit reaches maximum transmit power (+23 dBm) the operating point impact declines, as it does for greater call loading at the same path attenuation. *Thus, the impact calculation discussed in section 3.2.2 appears to be correct, as experimental results fall only 0.2 dB away.*

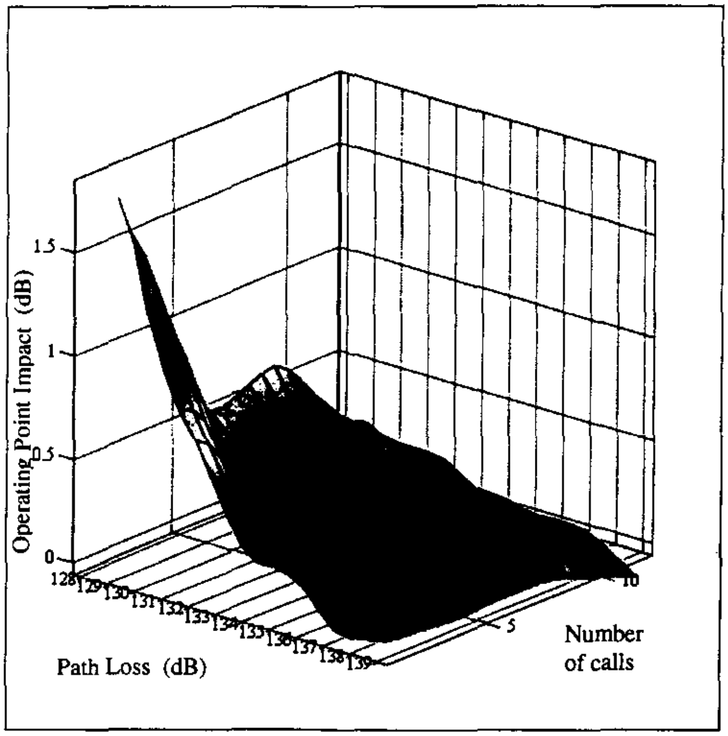


Figure 4.12 Operating point impact, 2 dB case, surface plot, Rural background noise

5 Operating point impact results

The surface plots for the 2 dB impact cases are shown in Figure 5.1 through Figure 5.4 below. The rural 2 dB case is repeated for convenience in referencing, and the Suburban, Urban and Dense Urban cases are shown for the first time in this section. It is useful to mention again that the operating point impacts are determined from the comparison of data files, the first file resulting from runs made without AMPS interferers present, and the second file having AMPS interferers present at a predetermined level. This comparison determines the effect of AMPS interferers had on the CDMA system's reverse operating point (which is really the CDMA mobiles' reverse path transmit power). This analysis is performed for variable CDMA system loading; from 1 to 12 full rate Markov CDMA calls.

5.1 Rural case

Examining the rural noise floor runs first (Figure 5.1), the 2 dB impact case exhibits the trends predicted by theory as noted previously, and a 1.8 dB impact where hand calculation had predicted 2.0 dB. As the traffic loading increases the 8, 10 and 12 call runs show small impacts, as expected.

The one call run results generally agreed well with expectations for each case. At minimum path attenuation, impacts (using three interferers at the levels indicated in Table 3.1.) were:

2 dB calculated, 1.8 dB actual
0.5 dB calculated, 0.38 dB actual

Note that the illustrated reverse operating point impact will always tend toward zero at the highest path attenuation values, as the phones are 'out of power' (running at +23 dBm output), and increasing path loss results in E_b/N_o decreases until the call drops. Likewise, operating point impact drops with increasing traffic load, as the AMPS interference level remains constant (yielding a constant-power contribution to CDMA noise floor) while CDMA self-interference (and its contribution to noise floor) dominates, theoretically diverging to infinity at the pole point.
Test runs were ended when subscriber units began dropping calls, and all phones would approach +23 dBm output power prior to call drop. Thus, in these last few dB, no operating point change is possible, but E_b/N_o is falling and call quality would be degraded. Thus, the emphasis is placed on the minimum path attenuation at the beginning of the runs, where operating point changes clearly manifest.

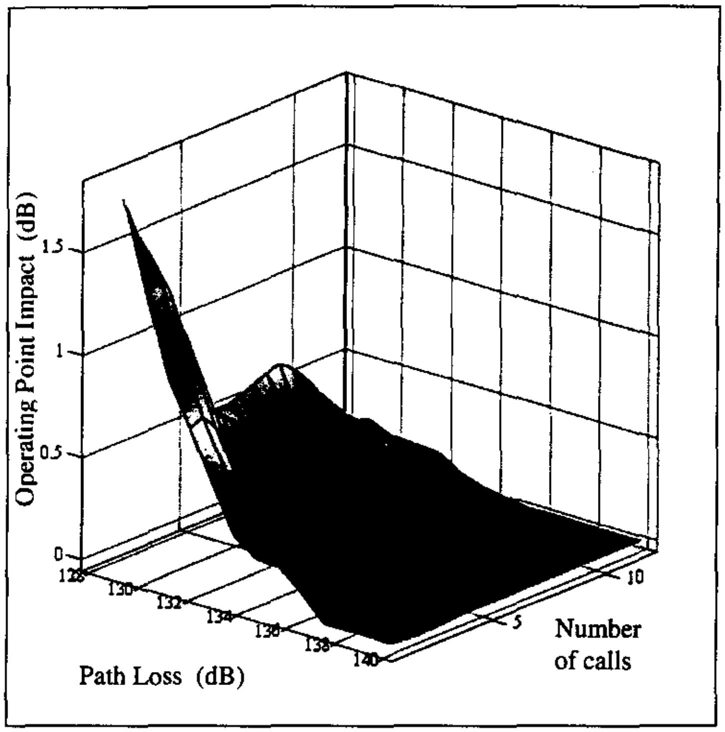


Figure 5.1 Operating point impact, 2 dB case, surface plot, Rural noise

5.2 Suburban case

Figure 5.2 shows the Suburban noise floor case. The noise floor was set 3 dB higher than for the Rural case, at -159 dBm/Hz. The 2 dB impact case is well behaved, with an actual impact of 1.5 dB observed for the one call run at minimum path attenuation. The expected trends manifest, with impact dropping as traffic loading increases. Impact also drops toward zero as path loss increases and the phones reach maximum transmit power.

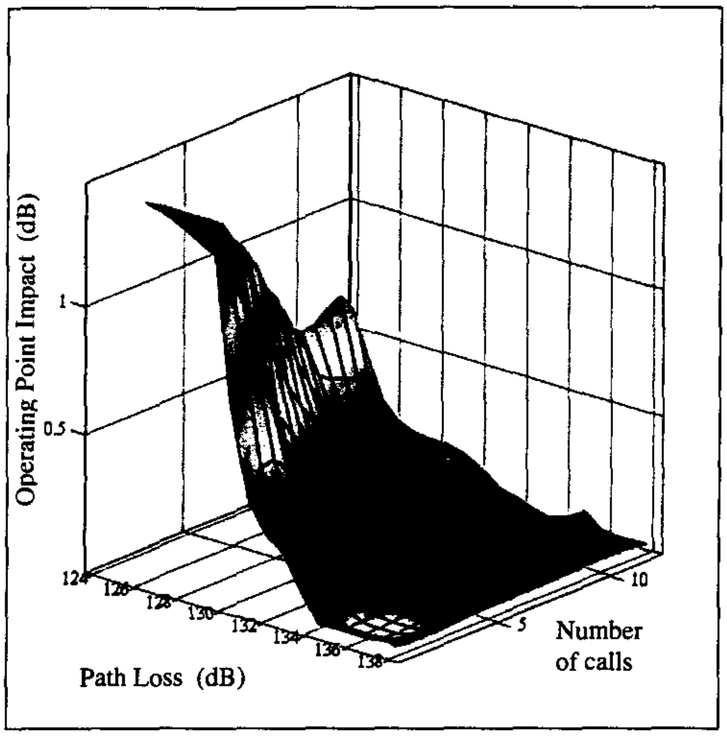


Figure 5.2 Operating point impact, 2 dB case, surface plot, Suburban noise

5.3 Urban case

Figure 5.3 illustrates the operating point impacts measured for the urban noise case. The 2 dB impact case shows less than the expected impact, peaking at 0.8 dB impact for the 4 call case. The one call case, where the largest impact was expected, measured 0.7 dB impact.

The 0.5 dB impact case appears more consistent with theoretical expectations, peaking at 0.39 dB impact.

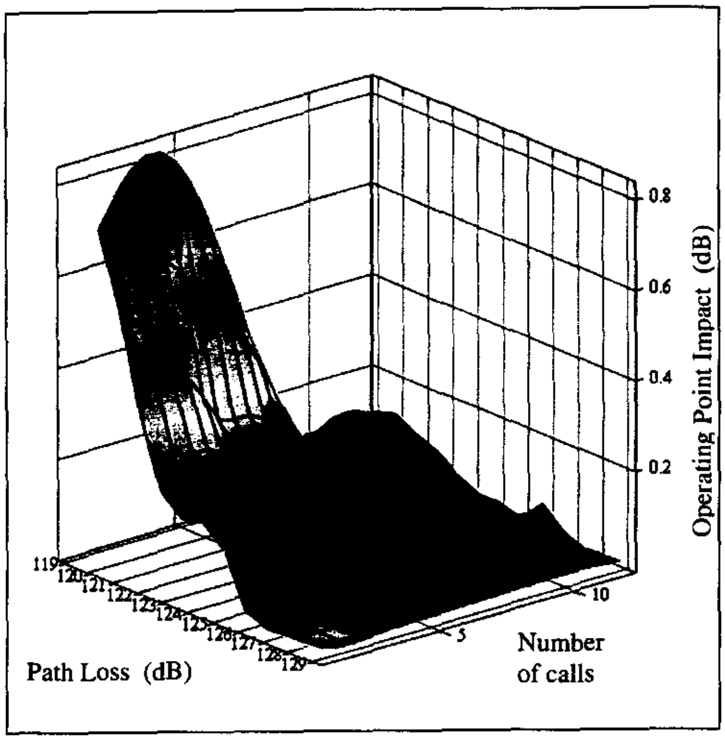


Figure 5.3 Operating point impact, 2 dB case, surface plot, Urban noise

5.4 Dense Urban case

As shown in Figure 5.4, the rising noise floor appears to further disrupt observation of AMPS signal impact in the dense urban case. The 2 dB impact case shows a *negative* impact of about 0.5 dB for a single call, decreasing to -1.5 dB for 8-10 calls.

The 0.5 dB impact case data was better behaved, and provided a measured impact of 0.25 dB for a single call, and a range of 0.14 dB to 0.3 dB for 4-12 full-rate Markov calls

As noted earlier, an extremely high noise floor is usually associated with high self-interference within the CDMA system. High self-interference in a well-designed CDMA system is often an indication that the pole point is being approached, and that reverse operating point may diverge abruptly upward. Cellular equipment manufacturers have added (proprietary) nonlinear software algorithms to mitigate such positive-feedback reverse power runaway.

This data suggests that some mechanism mitigated the operating point impact for the 2 dB test case, so it is *possible* that these proprietary software algorithms have been activated by the high noise floors, and operating point was not increased linearly to compensate for the interference. (Table 4.4 suggests this too, showing non-monotonic behavior between the 10 and 12 call runs.) It is also possible that AGC and A/D implementations in the cell site receiving equipment or other factors played a role in this deviation from theoretical performance. As cell site equipment design and software details are highly proprietary (and hence unavailable) it's not possible to make a positive determination of the mechanism(s) at work herein. However, as noted elsewhere in this report, the probability of an AirCell signal reaching the level of interference used in the 2 dB test case is essentially nil. Thus, the 2 dB impact case is largely of academic interest.

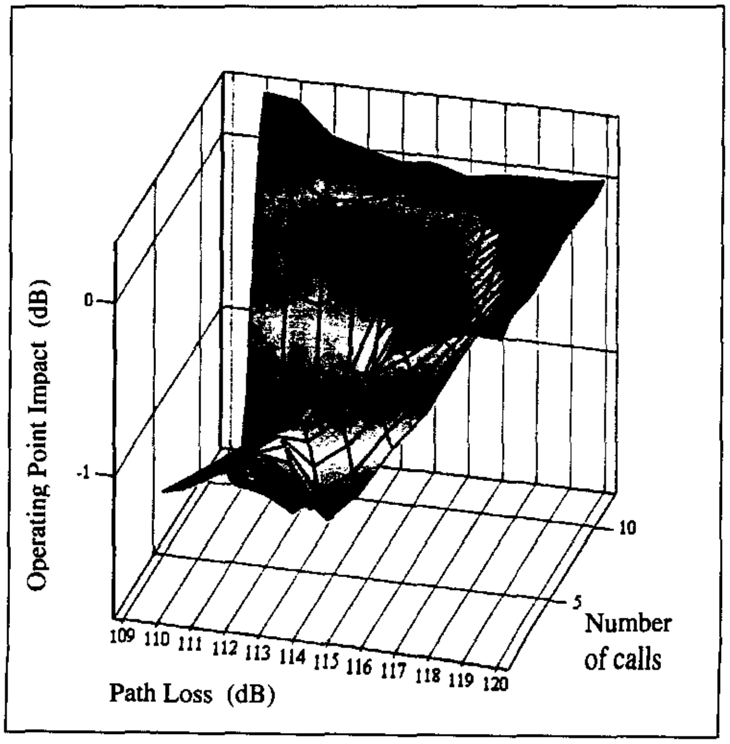


Figure 5.4 Operating point impact, 2 dB case, surface plot, Dense Urban noise

5.5 Operating point impact results summary

Two types of data were collected, the 'long term' data shown in Figure 5.1 through Figure 5.4, which represents comparisons between series of runs made 'with' and 'without' interference present. To observe the reverse channel operating point impact shown in these figures, runs (during which path loss was varied) were made with several levels of wideband noise, several CDMA call traffic volumes, with and without AMPS interference at precalculated levels. Each of these figures therefore represents data collected over hours or days. This method worked well for the 2 dB impact case.

To improve resolution for the 0.5 dB impact case, a 'short term' measurement strategy was employed. Varying numbers of CDMA calls were again set up in the presence of wideband noise and precalculated levels of AMPS interference, but the 'with' and 'without' AMPS interference data points were taken seconds apart. Thus, this data represents the immediate change observed as interference was added, after only a few seconds to allow power control settling.
Table 5.1 presents the measurement results.

Table 5.1 AMPS impact measurement results

Land Usage and Noise Floor	Estimated IS-95 Noise Floor / Operating Point Impact (Calculated impact)	AMPS Impact, Measured (dB) (Note that CDMA calls are full-rate Markov, so each represents CDMA self-interference typical of 2-3 subscriber calls with normal voice activity.)					AMPS Level at Reference Point (Precalculated and preset for each of 3 AMPS interferers)
		1 CDMA call	4 CDMA calls	8 CDMA calls	10 CDMA calls	12 CDMA calls	
Rural -162 dBm/Hz	0.5 dB 2 dB	0.20 1.8	0.38 0.67	0.30 0.67	0.21 0.42	0.21 0.21	-114.9 dBm -108.1 dBm
Suburban -159 dBm/Hz	0.5 dB 2 dB	0.55 1.4	0.31 0.69	0.33 0.69	0.26 0.76	0.10 0.21	-111.9 dBm -105.1 dBm
Urban -151 dBm/Hz	0.5 dB 2 dB	0.39 0.73	0.35 0.82	0.32 0.18	0.28 0.17	0.15 0.13	-103.9 dBm -97.1 dBm
Dense Urban -144 dBm/Hz	0.5 dB 2 dB	0.25 -0.56	* -1.4	0.14 -1.6	0.27 -1.5	0.30 0.29	-96.9 dBm -90.1 dBm

*Measurement not taken

Based on this data, the reverse channel operating point impact calculation method shown in section 3.2.2 is indeed an upper bound on that impact, which is valid when a single CDMA call is being placed. When CDMA traffic is higher, self interference plays a role and the impact from a (fixed) AMPS signal level is reduced.

Thus, calculations indicate that *three* AMPS interferers must be present at -114.9 dBm (or a single AMPS interferer at -110.1 dBm) to cause a co-channel CDMA cell carrying a *single* CDMA call to adjust reverse channel subscriber power by an average of 0.5 dB in a rural noise environment. *However, measurements show less actual impact than calculated.*
In noisier (more populated) environments and in situations where normal (higher) levels of CDMA traffic is carried, the impact is also less. Regardless, *any* operating point impact *will not* affect CDMA call E_b/N_0 or FER unless the subscriber unit is at maximum power, and can't compensate. A 0.5 dB impact will pass unnoticed even then, as the terrestrial fading environment will mask it.

6 Interference Assessment

6.1 CDMA interference susceptibility to AMPS signals

The mechanism by which AMPS reverse channel signals impact a CDMA system was discussed in section 2.1. This theoretical understanding was applied in section 3.2 to calculate the levels at which AMPS signals would impact the reverse channel operating point of a single CDMA call (no CDMA self-interference) by 2 dB, 0.5 dB, etc. This calculation approach was used to set AMPS signal levels for the cases tested. *(Real-world situations, involving traffic loading higher than one CDMA call per cell would include self interference effects, lowering the AMPS impact, a fact borne out by the results in section 5.)*

6.2 AMPS signal levels due to AirCell operations

On July 10-11 of 1997, AirCell staged a flight test in Texas and Oklahoma to evaluate the potential for its system to interfere with current ground based cellular systems. The tests were staged using four US Cellular cell sites in Texas and Oklahoma, and a pair of aircraft.

TEC Cellular was engaged by AirCell to participate in those tests, to act as an objective third party observer, to help structure the test, to record, retain, and disseminate the measured data. After disseminating the data, TECC analyzed the data and formed an opinion regarding its meaning and significance.

AirCell subscriber signal levels, as observed on the reverse channel by non-AirCell sites, referenced to the site antenna input jumper, were characterized in 1997 during flight testing in Texas and Oklahoma. These levels shared the same amplitude referencing point as that used for the CDMA test data presented herein, and can be directly compared to determine whether a potential for interference exists.

The levels observed in 1997 were presented in the document entitled Final Report, AirCell Flight Test, July 10-11, 1997 written by C. J. Hall and Ivica Kostanic of ***TEC Cellular, Inc.*** The report:

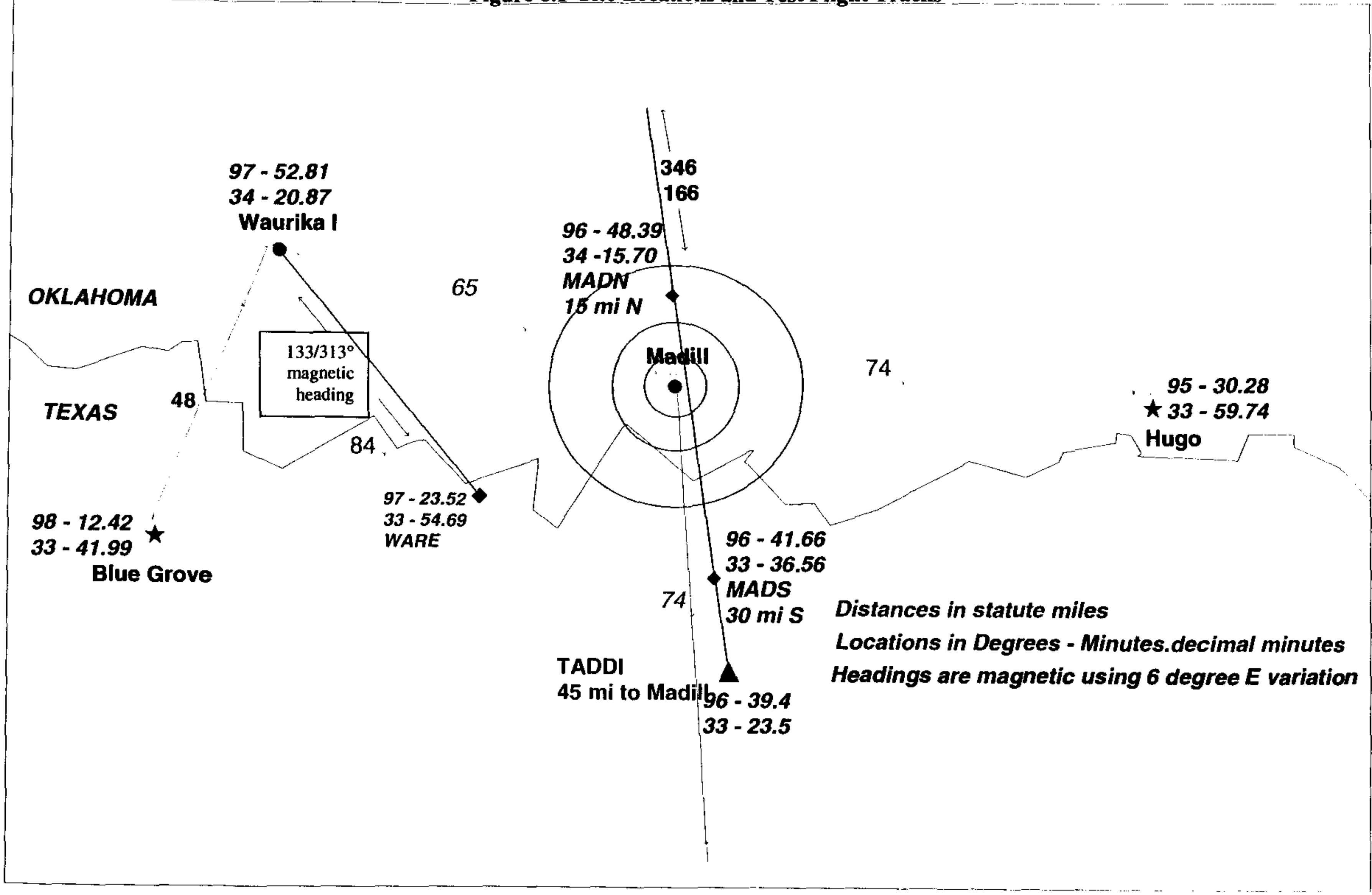
- Discussed the AirCell flight test objectives, how the test was structured, and the measures taken to ensure that the test data was accurate.
- Described the data taken, including site notes and the format of data files collected.
- Described data postprocessing accomplished prior to distribution of the data on CD to all parties.
- Described ***TECC***s analysis of the data.
- Presented ***TECC***s observations and conclusions that follow from the data analysis.

During the 1997 test, data was taken for a series of flights using two aircraft, one a Cessna 414 belonging to Mr. Jimmy Ray of AirCell and the other a rented Cessna Conquest Turboprop. The 414 was used for testing below 10,000 feet, and the Conquest was used for testing from 10,000 feet MSL through flight level 350 (approximately 35,000 feet).

Test calls were established at one of two serving AirCell cells, each equipped with a typical omnidirectional installation and a smart antenna system, which was said to reduce the required reverse channel transmit power by approximately 10 dB relative to the omnidirectional antenna system. By making test runs over the same flight path, at the same altitude, during the same test flight with one antenna system and then the other, data was collected supporting this claim.

After an AirCell test call was set up, the aircraft would make a constant altitude pass inbound or outbound over an instrumented 'observer' cell (Madill or Waurika). Site locations and flight paths are shown in detail in Figure 6.1. These observer cells were situated 48-74 miles away from the AirCell site carrying the call, and represent non-AirCell ground sites (subject to possible interference) in the handoff region between AirCell cells. This handoff region is the area in which reverse channel (aircraft transmit) power requirements are expected to be highest in a completed AirCell system. So, flights approaching and passing directly overhead such observer cells should subject those observers to levels of interference comparable to the highest levels one would observe in a completed system.

Figure 6.1 Site Locations and Test Flight Tracks



The 1997 test was structured to quantify interference that the AirCell system was likely to produce. The report addressed this question in three phases. The first phase was the actual flight test, along with the associated data reduction. This phase quantified the potential for interference resulting if:
1) The AirCell customer is airborne,
2) The AirCell customer is placing a call,
3) The AirCell voice channel is co-channel to one used at the ground cell being observed,
4) The co-channel ground cellular channel is carrying a simultaneous call,
5) The aircraft passes near or overhead the ground cell of interest

Clearly, all of these events must simultaneously occur for interference to be *possible*, so the test conditions included all the factors above, except (4), which would have prevented measurement of the AirCell signal level reaching the observer cell site.

The test was complicated by the fact that AirCell reverse channel signals were frequently so weak that they fell at or below the noise floor of the measurement equipment. So, the measured value was often the noise floor itself. This made it difficult to accurately determine the AirCell signal strength statistics at Madill or Waurika. The signal strengths described below are 'signal plus noise' and *not* AirCell signal level alone.

A summary of the test runs and the mean signal plus noise values recorded using the operational cell site collinear antennas and multiple receivers appears below. These tables excerpted from the 1997 flight test report indicate run number, test conditions, and the average power measured three ways. Full details regarding data collection setup and equipment calibration are presented in the 1997 report, and are omitted here for brevity. Nominal altitude is expressed in feet above Mean Sea Level (MSL) as measured by the aircraft altimeter. At altitudes above 14,000 feet, the barometric reference was set to 29.92" Hg, and local measured value for altitudes below 14,000 feet, per FAA procedures. All runs were constant altitude.

Leg designations refer to the map in Figure 6.1. Dynamic Power Control (DPC) states whether the reverse channel was automatically set to the minimum acceptable level ("ON") or run at full available power ("FIXED"). All runs summarized below were with DPC on. Four runs were made on July 11, 1997 with "FIXED" transmit power at 70 mW in order to elevate the observed signal level above the measurement noise floor, permitting accurate path loss characterization. Those runs are omitted here, as they do not represent normal AirCell system operation. (Aggressive power control is central to the AirCell interference reduction strategy.) Serving Cell antenna refers to the use of either passive omni or active beamsteering ("Smart") reverse channel receive antennas at the AirCell site serving the test call, *not* at the observer site.

Received (interference) signal plus noise power was measured three ways at Madill, and two ways at Waurika, using redundant spectrum analyzers and Grayson receivers.

At Madill, four HP8591E spectrum analyzers were used, two recording data using 10 kHz resolution bandwidth and two recording at 30 kHz resolution bandwidth, using both site diversity receive antennas. Preamplifiers and multicouplers were used to permit these multiple connections to each antenna and reduce the normally high noise figure exhibited by spectrum analyzers. The gain of these items was normalized out. A Grayson test receiver was also used for data collection.

At Waurika, two spectrum analyzers were used, along with a Grayson test receiver. Waurika had two signal paths, one using a site omni receive antenna, and the other using a horizontal polarization panel antenna, which is occasionally used by cellular carriers for polarization diversity on receive.

Table 6.1 Cessna Conquest, July 10, 1997

Run Number	Nominal Altitude*	Leg (See map)	DPC	Serving Cell Antenna System	Avg Pwr dBm (30kHz)	Avg Pwr dBm (10kHz)	Avg Pwr dBm Grayson
10A	15,000	MADN to MADS	ON	Smart	-124.2	-129.0	N/A
10B	15,000	MADS to MADN	ON	Smart	-124.3	-129.4	-130.5
10C	25,000	MADN to MADS	ON	Smart	-124.6	-129.6	-130.4
10D	25,000	MADS to MADN	ON	Smart	-124.6	-129.5	-130.8
10E	35,000	MADN to MADS	ON	Smart	-123.6	-128.9	-130.9
10F	35,000	MADS to MADN	ON	Smart	-123.9	-128.9	-130.8
10G	35,000	MADN to MADS	ON	Omni	-123.9	-128.6	-128.9
10H	35,000	MADS to MADN	ON	Omni	-124.0	-129.0	-130.0
10I	25,000	MADN to MADS	ON	Omni	-123.9	-128.4	-127.8
10J	25,000	MADS to MADN	ON	Omni	-124.2	-128.9	-129.3
10K	15,000	MADN to MADS	ON	Omni	-123.6	-128.2	-128.1
10L	15,000	MADS to MADN	ON	Omni	-123.3	-128.0	-129.2

**Subject to weather/ATC induced changes as noted in test logs*

Table 6.2 Cessna 414, July 10, 1997

Run Number	Nominal Altitude*	Leg (See map)	DPC	Serving Cell Antenna System	Avg Pwr dBm (30kHz)	Avg Pwr dBm (10kHz)	Avg Pwr dBm Grayson
10M	5,000	MADS to MADN	ON	Smart	-124.3	-129	-129.7
10N	5,000	MADN to MADS	ON	Smart	-124.2	-129	-130.3
10O	5,000	MADS to MADN	ON	Omni	-123.4	-127.6	-128.2
10P	5,000	MADN to MADS	ON	Omni	-123.7	-128.3	-128.3

**Subject to weather/ATC induced changes as noted in test log*

Table 6.3 Cessna 414, July 10, 1997

Run Number	Nominal Altitude*	Leg (See map)	DPC	Serving Cell Antenna System	Avg Pwr dBm (10kHz) Hpol ant	Avg Pwr dBm (10kHz)	Avg Pwr dBm Grayson
10R	5,000	WARE to WAR	ON	Omni	-121.3	-127.6	-132.2
10S	5,000	WAR to WARE	ON	Omni	-120.8	-127.0	-132.2
10T	5,000	WARE to WAR	ON	Smart	-127.0	-128.0	-131.2
10U	5,000	WAR to WARE	ON	Smart	-125.3	-127.8	-129.0

**Subject to weather/ATC induced changes as noted in log*

The levels shown in Table 6.1 through Table 6.3 reference the output of the antenna system at the site. That is, power has been adjusted to the value it would read at the output of the 1 5/8" coaxial cable entering the shelter. This is the same reference point - the antenna jumper input to the Antenna Interface Frame - as was used with the CDMA system.

(For 10kHz resolution bandwidth, the thermal noise floor was -134 dBm. The noise figure calculated for the Madill test setup was 4.2 dB, so the measurement noise floor was about -129.8 dBm. For 20 kHz BW, the measurement noise floor rises to -126.8 dBm, and for 30 kHz, it is -125.0 dBm.)

These tables summarize the 1997 test results well... Note that the high altitude runs (15,000 feet and above) observed with the spectrum analyzers had average recorded amplitudes within 2 dB of the measurement noise floor. To disturb the noise floor by 2 dB, an interfering signal would have to be approximately 2.3 dB *below* the measurement noise floor.

This low received AirCell signal strength is reasonable, considering the observer site was crosspolarized and that aircraft transmitter power averaged 4.5 mW when the omni serving cell antenna was in use, and only 0.5 mW when smart antennas were used.

The low altitude runs at Madill with dynamic power control 'on' were similar. The average received power recorded was within 2.4 dB of the measurement noise floor for both 10 and 30 kHz bandwidths, so the average received power from the AirCell call was *still below the noise floor.* This isn't terribly surprising, as aircraft transmitter power averaged about 2.5 mW with an omni serving cell, and 0.34 mW using smart antennas at the serving cell.

The low altitude runs at Waurika (10R through 10U) did not collect 30 kHz bandwidth data. The spectrum analyzer data was 10 kHz bandwidth, collected on the vertically polarized omni antenna. The average level was within 3 dB of the measurement noise floor, indicating the AirCell call averages a received power *at or below the measurement system noise floor.*

The observed probability density for received signal level as an aircraft passed near or over the observer site was presented in histogram form in the 1997 report, with abscissa of signal strength (in dBm, referenced to the coax entering the cell site shelter) and an ordinate showing the number of measurements at that level.

Given that aircraft speed was essentially constant, these points were evenly weighted vs distance, with one caveat: At Madill, the receive antennas were Kathrein model 740198R2s. These antennas are reflectorized collinears, with a mild directional pattern. They have perhaps 10 dB front to back ratio, and the antennas were oriented facing North. As such, Madill data *may* show higher gain in that direction, though cross-polarized (horizontal) sensitivity relies more on element pattern, as the vertical reflector rod does less to produce a front to back ratio.

The flight paths past Madill began 30 miles to the South, passed almost overhead the site, and ended 15 miles North of the site. (Or vice versa on Southbound passes.) This suggests that Madill measured data, compared to a symmetric pass beginning and ending at the same range, over-represented ranges under 15 miles. There were twice as many data points taken (assuming constant aircraft speed) under 15 miles as there were from 15-30 miles. Thus, the histograms of aircraft data over-represent the interference threat relative to a caller approaching, passing nearly overhead, and then receding into the distance. (With a call up the entire time.)